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Phase II Report - January thru June 1973

Status and Technical Progress

EVALUATION OF ERTS DATA FOR CERTAIN HYDROLOGICAL USES

Principal Investigator	Donald R. Wiesnet
Coinvestigator	David F. McGinnis
Associate	Michael Matson

NOAA/NESS/ESG
Suite 300, 3737 Branch Ave., S.E.
Washington, D.C. 20031

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Wiesnet, D.R. and McGinnis, D.F.

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16. Abstract
Mapping of snow cover using ERTS-1 data proved to be six times faster than that done from U-2 photography. However, NOAA-2 VHRR snow cover mapping was almost as fast as ERTS-1, and it is available more frequently. Ice conditions in the Great Lakes can be readily determined by ERTS-1. Ice features characteristic of thawing conditions such as rotten ice, lack of pressure ridges, brash belts and compacted ice edges can be identified. A great decrease in apparent reflectivity is band 7 as compared to band 4 also indicated melting conditions. Using sidelap from two successive ERTS-1 images of Lake Erie (February 17 and 18, 1973) a measure of ice movement was made, agreeing closely with the estimate from conventional methods. The same imagery permitted tentative identification of the following features: shuga, light and dark nilas, fast ice, icefoot, ice breccia, brash ice, fracturing, ridging, rafting, sastrugi, thaw holes, rotten ice, ice islands, dried ice puddles, hummocked ice and leads.

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1.0 INTRODUCTION

1.1 Purpose and Objectives.

Two areas have been singled out for special hydrologic study in this investigation. One is the Sierra Nevada region; more specifically the American and the Feather River basins. Both these basins are part of the Sacramento River drainage in California. The other geographic area is the Lake Ontario basin, which is being intensively studied under the International Field Year on the Great Lakes Program (IFYGL).

The American River is fed by the Sierra snowpack, a highly managed and rather important water resource. Snow measurements within the rugged highland areas of the basin are few, except for occasional aircraft photo-reconnaissance surveys. Nevertheless, eight remote readout stations for measuring snow can be monitored during satellite transits. Our objective in the Sierra Nevada area is to evaluate the capability of ERTS sensors to monitor snowmelt on 18-day-cycle basis, to determine the feasibility of direct quantitative assessments of water storage in reservoirs and/or the snowpack as snow.

The Lake Ontario basin is a large temperate region lake. Our objective is to assess, as quantitatively as possible, the hydrologic information that can be extracted from ERTS sensors. Specifically we plan to compare ground truth and aircraft measurements with ERTS data in an investigation of soil moisture in several farming areas near Syracuse, N.Y.

Comparison of ERTS sensors and NOAA-2 sensors will permit evaluation of the effect of the 18-day cycle on monitoring hydrologic phenomena.

1.2 Summary of Work Performed During Working Period.

1. Using the Zoom Transfer Scope, 70-mm ERTS-1 chips were employed

to map the snow extent in the American River basin for each band (MSS 4-7) from imagery of 16 March 1973. A second map using MSS band 4 was prepared from 3 April 1973 data, and a third map from 9 May 1973 data was also prepared.

2. For comparison, 13 snow extent maps for the American River basin were prepared from NOAA-2 VHRR data. A melt rate curve was developed.

3. A preliminary comparison of results of repeated measurements of snow extent using both ERTS-1 and NOAA-2 VHRR data was completed.

4. Two photo mosaics of the Feather River Basin were made from ERAP U-2 imagery, 6 March 1972, and 2 May 1972.

5. Snow mapping of the L. Ontario basin was completed by means of the Zoom Transfer Scope using imagery from 9-12 January 1973. Frozen and open-water areas of lakes were also noted.

6. Using Computer Compatible tapes (CCT) attempts were made to obtain numerical printouts for 11 October 1972 of the Scipio Center, N.Y. Test Site for Soil Moisture determination, programming and computer problems have not yet been surmounted. Near the end of the period a grid-point numerical printout of MSS band 6 appears to be the best product yet obtained. It is about 1:25,000 scale. It has not yet been completely examined. Multispectral imagery and thermal IR from aircraft have now been received and are available for comparison with the ERTS-1 CCT.

7. ERTS imagery of Lake Erie ice has been used to check the ground resolution of NOAA-2's VHRR. High contrast cracks that appear on both images taken minutes apart were measured on an ERTS-1 image (18 Feb 1973).

2.0 MAIN TEXT

2.1 Data received from NASA

Data in the form of 70-mm chips has been received regularly but the sequence of data received is not correlatable with the chronology of collection. Requests for CCT take about five weeks to be filled including shipping time. The requests for ERAP U-2 data have been remarkably quick, with color film transparencies taking usually less than a month, and black-and-white film taking about two or three weeks.

2.2 Other data

2.2.1 The NESS photolab is now backlogged on b/w print work from ERTS-1, and a contract is under negotiation to relieve this pressure and backlog.

2.2.2 Soil moisture aircraft data from Spectral Data Corp. consisting of multispectral film and ground-based telespectra-radiometer data have been received. Thermal (3-5 and 8-14μm) IR from Dadaelus Inc. has been received. Preliminary results of ARMS gamma-ray airborne survey have been received. Results of the soil moisture laboratory analysis are now available.

2.2.3 NOAA-2 VHRR data is received daily at Suitland, Md. in the visible (.6-.7μm) band and in the thermal (10.5-12.5μm) band. More complete details of this system and sensor are given in the prior Phase II Report (Wiesnet and McGinnis, 1973).

2.3 Analysis Procedures

2.3.1 Snow Mapping

a) U-2 photography. All available color IR (.51-.90μm) photography of the Feather River Basin was examined to determine which of a number of overflights contained the best variety of snow, ice and no-snow areas. The overall quality of the film (i.e., the absence of scratches, the exposure, the image contrast, etc.) was an important factor also considered. Flight

number 72-036 (accession number 00221) taken on 6 March 1972 was ultimately selected. Color IR was selected as offering better contrast between snow and no-snow areas when compared to the other spectral bands. The scale of the photos was determined to be 1:445,000 by using the following formula:

$$\text{Photoscale reciprocal} = \frac{12H}{f} \quad \text{where}$$

H = Altitude of aircraft (in ft.) and

f = focal length of camera (in inches)

A topographic map of the basin (1:250,000) was used as a base map in the Zoom Transfer Scope and each 70-mm color aerial photo was also mounted in the Zoom Transfer Scope, and registered at the scale of 1:250,000 to the base map, by using the photo optical enlargement, image rotation and stretch adjustments of the ZTS. Edge distortion of the photos was evident, and wherever possible only the central portion of the photo was used for mapping. Twenty-three photos were required to map the basin. It should be noted that "data holidays" in the coverage at the edges of the basin precluded 100% coverage of the basin. Frame overlap and side lap from photo to photo was approximately 10%, providing about 40% total overlap on each frame.

Snow was mapped as "snow covered areas", snow in light forest areas, and no-snow areas. Ice on lakes was also mapped. Ice-covered rivers were indicated by dark lines.

The order of precedence for image/map alignment were: 1) highways, 2) rivers and streams. Lakes are best avoided as the outlines change rapidly when lake volumes change. In areas of overlap best-fit adjustments were necessitated by the variable tip and tilt of the aircraft as well as the altitude.

Comparison of the snow map prepared on the basis of the U-2 photography of 6 March 1972 with limited ground truth is shown in table 1. The Frenchman Hill anomaly is attributed to the fact that this area was on the edge of both aerial photos hence positional error of the snowline is likely. Unless photogrammetric techniques are used, this type of error is inherent in mapping from air photos. A line shift of only 1/2 inch (i.e., about two miles on the ground) to the west would place Frenchman's Hill within the area of snow in light forest.

Snowline elevations north and south of Sierra Valley were determined from the snow map. Twelve orbitrarily selected points were chosen where the snowline crossed contour lines on the north slope and twelve on the south slope. The mean elevation of the south-facing slope snowline was 5,800 ft msl; the mean elevation of the north-facing slope snowline was 5,900 ft. One would expect, theoretically, that this condition would be reversed as the south-facing slopes receive greater solar energy at this time of year in the northern hemisphere than do the south-facing slopes. The deep shadow effect in steep-walled canyons and cliffs may be responsible for this anomaly as well as the previously described position problems.

A total of 22 man hours of work went into the map - 4 of which were used to prepare and mount frames prior to the actual mapping operation.

Two uncontrolled photomosaics of the Feather River basin were prepared from U-2 photos flown on 6 March 1972, the same date as the map, and 2 May 1972. The original negatives at 1:445,000, enlarged prints (1:250,000) scale (black and white) were used and were laid over the base map. Edge distortion, variations in contrast, variable sun angles, and "data holidays" due to misalignment of flight lines were some of the problems encountered. Approximately five man-hours were required for each mosaic.

b) ERTS-1 imagery of the Feather River basin for 29 November 1972, 4 January 1973, and 22 January 1973 was utilized for snow extent mapping. The 1:3,369,000-scale 70-mm ERTS chip (MSS band 4) was enlarged to 1:500,000 in the ZTS and mapped directly on the base map in the same manner as described in section 2.3.1.a). The ERTS-1 data was much easier to handle, mount and register to the base map. It was much quicker as well. Half an hour for setup and three hours for mapping produced a finished map. This represents a 6:1 ratio in favor of the ERTS-1 snow mapping over the use of high altitude aerial photos in terms of man-hours saved. Furthermore the shadow problem is greatly reduced, the positional accuracy of the snow line is much more consistent, and the light forest cover tends to be less of a problem with reduced ground resolution.

Snow extent maps of the American River basin were also made from ERTS-1 imagery for 16 March, 3 April, and 9 May 1973 (see figs. 1-3).

c) NOAA-2 VHRR visible band imagery has been acquired over the Sierra Nevada daily. Thirteen cloudfree images over the American River basin were selected for analysis, using the ZTS as described previously. Rectification in this case, was much more difficult owing to the large distortion found in the imagery especially at the extreme edges of the image. The images were enlarged usually about 7 times and "stretched" to make the drainage fit the drainage pattern of the map. The results are shown as a snowmelt plot in fig. 4. These data will be compared with discharge data, which has not yet been secured. As of 1 July 1973 a trace of snow is still visible on Pyramid Peak (3043 m) in this basin.

d) Discussion. In terms of man hours, ERTS-1 is 6 times faster than U-2 snow cover mapping, but NOAA-2 VHRR snow cover mapping is almost as fast as ERTS-1, but it is available more frequently. With systematic

scheduled coverage (and with no clouds) daily mapping of snow cover could be accomplished. The results of repeated trials of both ERTS-1 and VHRR snow mapping attempts are given in table 2. The greater ground resolution of ERTS-1 and its cartographic fidelity make it outstanding as a snow mapping satellite. It has no peer in this respect. Yet to be of operational service, NOAA/NWS requires data at least weekly, preferably biweekly. For operational purposes, NOAA-2's daily visible and twice daily thermal IR coverage appear to be more useful for operational snow mapping and prediction. The great value of the ERTS-1 is its ability to provide a reliable check or "calibration standard" to which the NOAA-2 satellite sensors can be compared and corrected. Another obvious drawback to the use of ERTS-1 data for predictive purposes is the lag time between receipt of the data and its arrival in the hands of the concerned principal investigator.

2.3.2 Snow and Ice Melt Detection.

The use of the near IR (.7-1.3μm) in combination with the visible band data (from Nimbus-3) can be used to detect melting snow (Strong, McClain and McGinnis, 1971) (Wiesnet and McGinnis, 1972) (McGinnis, 1972). As these bands are present on the ERTS-1 MSS attempts have been made to identify melting snow in mountainous areas (Wiesnet, 1973; Meier, 1973; and Barnes, in press) using ERTS-1 MSS bands 4 (.5-.6μm) and 7 (.8-1.1μm).

ERTS-1 MSS imagery over Lake Erie (8 March 1973) has been examined (images #1228-15422-4 and -7) for melting ice. The ice field in band 4 has high reflectance but the ice field has a "lacy" appearance resulting from many thaw holes, and a characteristic of "rotten" ice, i.e., ice deteriorating under warm temperatures. Table 3 shows the air temperatures and wind data for stations near Lake Erie before and after the ERTS-1 pass (1542 GMT). Note that no station reported below freezing temperatures.

Other ice features tentatively identified on these images are: grounded ice west of Pt. Aux Pins, Ont; an icefoot near Marblehead, O.; and along the east edge of Pt. Pelee, Ont. the compacted ice edge of the southern edge of the icefield northwest of Cleveland, O.; the young ice-snow sheet broken up by wave action east of Pt. Aux Pins; and brash belts oriented almost N-S between Painesville and Astabula, O.

In theory, water temperatures of the lake ought to be 0°C with melting ice present. Appropriately, when NOAA-2 Very High Resolution Radiometer images were checked, the lake appeared to be at a uniform temperature in the thermal IR image (figure 5) and yet ice was evident in the visible band image at 1451 GMT.

Because it was apparent that ERTS-1 prints in bands 4 and 7 had been developed and processed differently, we attempted to treat the two negatives in a uniform fashion to get a better idea of the difference in reflectivity. Figure 6 shows two MSS images of the melting ice field that were exposed and developed simultaneously under the same photographic constraints. Note the identical calibration of the step wedges at the bottom of each image. The decreased reflectance in the near-IR (band 7) is rather pronounced under equal development conditions. However, it must be noted that the original negative was developed by NASA GSFC, and was undoubtedly processed differently in the two bands owing to contrast and tonal differences. Digital tape printouts are expected to provide a more quantitative comparison of the reflectance in these two spectral bands.

Summary of significant results.

Ice conditions in the Great Lakes can readily be determined by ERTS-1. Ice features characteristic of thawing conditions such as rotten ice, lack

of pressure ridges, brash belts and compacted ice edges, can be identified. A great decrease in apparent reflectivity in band 7 as compared to band 4 also indicates melting conditions. Air temperatures both before and after the satellite pass confirm that melting conditions are at hand. NOAA-2's VHRR confirms a uniform lake temperature in the lake one hour and nine minutes prior to the ERTS-1 pass.

2.3.3 Lake Ice dynamics

As shallowest of the Great Lakes, Lake Erie is subject to more extensive freezing and ice formation than any other of the Great Lakes. Freeze-up tends to be much more sudden than break up and melting, which, however, can also be rather dynamic. For monitoring changing ice conditions ERTS-1's 18-day revisit cycle again presents problems, as ice formation movement, and breakup may all occur within a very short time span and be unrecorded by the ERTS-1 satellite sensors.

Despite this possibility, excellent images of Lake Erie ice were recorded on 17-18 Feb 1973 and again on 8 March. Strong (personal communication) has already reported on an analysis of ice movement from changes noted on the sidelap portions of the images on the 17th and 18th.

Weather conditions may preclude this type of sidelap analysis of movement in many cases, but by use of structural analysis of the fracture patterns, it is believed that reasonably good estimates of ice movement may be made. Antecedent meteorological conditions are vital to such an analysis as they are an overriding factor in determining the physical conditions and movement of the ice.

As an example, imagery of the Cleveland area was analyzed by measuring the displacement of a series of characteristic ice edges which had broken

from fast shore ice within the preceding 24 hours.

Preliminary estimates of ice movement range from 800 m/hr to 300 m/hr, (0.4-0.2 knots) to the west. Strong's sidelap analysis of motion gave figures ranging from 1500 m/hr to 500 m/hr (.8 to .3 knots). Considering the fact that the onset of motion is not precisely known, the figures are in rather good agreement.

The 100-m resolution ERTS-1 makes it outstanding for synoptic ice pack studies on the Great Lakes.

2.3.4 Identification of ice features.

The following ice features have been tentatively identified from the 17-18 Feb and 8 March 1973 ERTS-1 MSS images of Lake Erie and Lake Ontario (Note that ground truth is not available for verification.): Shuga, light and dark nilas, fast ice, icefoot, ice breccia, brash ice, fracturing, ridging, rafting, sastrugi, thaw holes, rotten ice, ice islands, dried ice puddles, hummocked ice and leads.***

These terms are defined in WMO Sea-Ice Nomenclature WMO/OMM/BMO no. 259 TP 145.

2.3.5 Soil Moisture.

Despite a large effort, results of the soil moisture experiment do not seem close at hand. The data collected on 11 Oct 1972 at the Scipio Center, New York, NOAA test site include gravimetric soil moisture measurements, gamma-ray, overflights, multispectral camera coverage and thermal IR scanners. CCT printouts have been made of concurrent ERTS-1 data but programming problems have not yet been solved. Data reduction is nearly complete but analysis is expected to be long and difficult.

***Significant Result

Using CCT, attempts were made to obtain numerical printouts for 11 Oct 1972 of the Scipio test site for soil moisture studies. However, tape and programming problems have not yet been surmounted. In June a grid-point numerical printout of MSS band 6 appears to be the best product yet obtained. It is about 1:25,000 scale but has not yet been evaluated fully. Multispectral imagery and thermal IR imagery are now at hand for comparison with the ERTS-1 numerical printouts.

3.0 NEW TECHNOLOGY

No technology was developed during this period.

4.0 PROGRAM FOR NEXT REPORTING PERIOD

4.1 Sierra Nevada

Additional snow extent maps of Feather River and/or the American River basin will be made. Efforts are underway to secure ground truth and to compare this with the satellite imagery. 1972 data on hand will be compared with 1972 U-2 imagery. According to VHRR satellite data, snow is now gone from the American River except for a trace at Pyramid Peak (3043 m).

4.2 Lake Ontario basin

4.2.1 Studies of the CCT digital printouts will begin for the soil moisture studies at the NOAA test sites in the IFYGL basin. Correlation with limited point data ground truth will be investigated.

4.2.2 VHRR will be used for snow mapping and comparison with ERTS-1 imagery in this large basin.

4.2.3 Aircraft multiband photography and ground telespectraradiometer reading over the test site were not compared with ERTS-1 data (CCT) last period as the tapes had to be returned for new copies which are now at hand. We hope to accomplish this objective in the next six months.

4.2.4 Thermal imagery of the test site will be analyzed. It has been received.

4.2.5 Additional studies of ice in the Great Lakes will be made, using computer compatible tapes.

5.0 CONCLUSIONS

5.1 ERTS-1 70-mm chips can be used for snow mapping in moderate sized basins such as the American and Feather River basins in California. They are especially useful to check the accuracy of the daily VHRR data from NOAA-2, which is not as precise cartographically as the ERTS-1 data.

5.2 Snow cover maps of river basins are at least six times cheaper when done by ERTS-1 than when done by high-altitude aerial photo surveys.

5.3 The NOAA-2 VHRR snow cover maps are about as economical as the ERTS-1 snow cover maps but are probably not as accurate. Preliminary estimates are that VHRR maps are usually within 5% of the ERTS-1 figure.

5.4 ERTS-1 is the most outstanding lake ice reconnaissance platform yet devised. The detailed images of lake ice, and lake ice features exceeds any prior sensor platform combination in terms of interpretability and information content. By using it in conjunction with NOAA-2, it ought to revolutionize the ice forecasting ability of NOAA's Lake forecasters.

5.5 Quick-look estimates of the capability of ERTS-1 to sense soil moisture in the NOAA test site area are not particularly encouraging. Certainly more work and detailed CCT analysis is needed.

6.0 RECOMMENDATIONS

6.1 Install a thermal scanner on ERTS-B.

7.0 REFERENCES

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6. Meier, M.F., 1973, New Ways to Monitor the Mass and Areal Extent of Snowcover, Symposium on Approaches to Earth Survey Problems through the use of Space Techniques, COSPAR, Konstanz, West Germany.

7. Barnes, J.C., (in press), Use of ERTS Data for Mapping Snow Cover in the Western United States, Symposium on Significant Results Obtained from ERTS-1, March 5-9, 1973, New Carrollton, Maryland.

Site	Water Content of Snow (inches)	U-2 Map
Walker Plains	12.7	Snow in light forest
Frenchman Hill	35.4	No snow
Gold Lake	35.6	Snow in light forest
Grizzly	22.3	Snow in light forest

Table 1. Comparison of snow map of Feather River basin with ground truth furnished by R. Burnash, NOAA/NWS River Forecast Center, Sacramento, Calif.

AMERICAN RIVER BASIN, CALIFORNIA

DATE	ERTS-1	NOAA-2
3/15/73	46%	46%
4/2/73	48%*	45%*

*Average of 4 trials, 2 operators. Each trial consists of 3 areal measurements.

Table 2. Preliminary comparison of snow mapping by ERTS-1 and NOAA-2.

STATION	WIND (°F)			WIND (KNOTS)		
	1200Z	1500Z	1800Z	1200Z	1500Z	1800Z
Erie	45	54	56	SW 10	SW 10	NW 20
Cleveland	43	55	61	SW 5	SW 5	W 10
Toledo	39	52	61	S 10	W 5	W 10
Detroit	38	50	57	SW 5	SW 5	SW 20
London, Ont.	38	47	52	SW 5	W 15	W 20
Buffalo	42	49	54	SW 5	SW 15	W 20

Table 3. Meteorological data before and after the ERTS-1 pass on 8 March 1973.

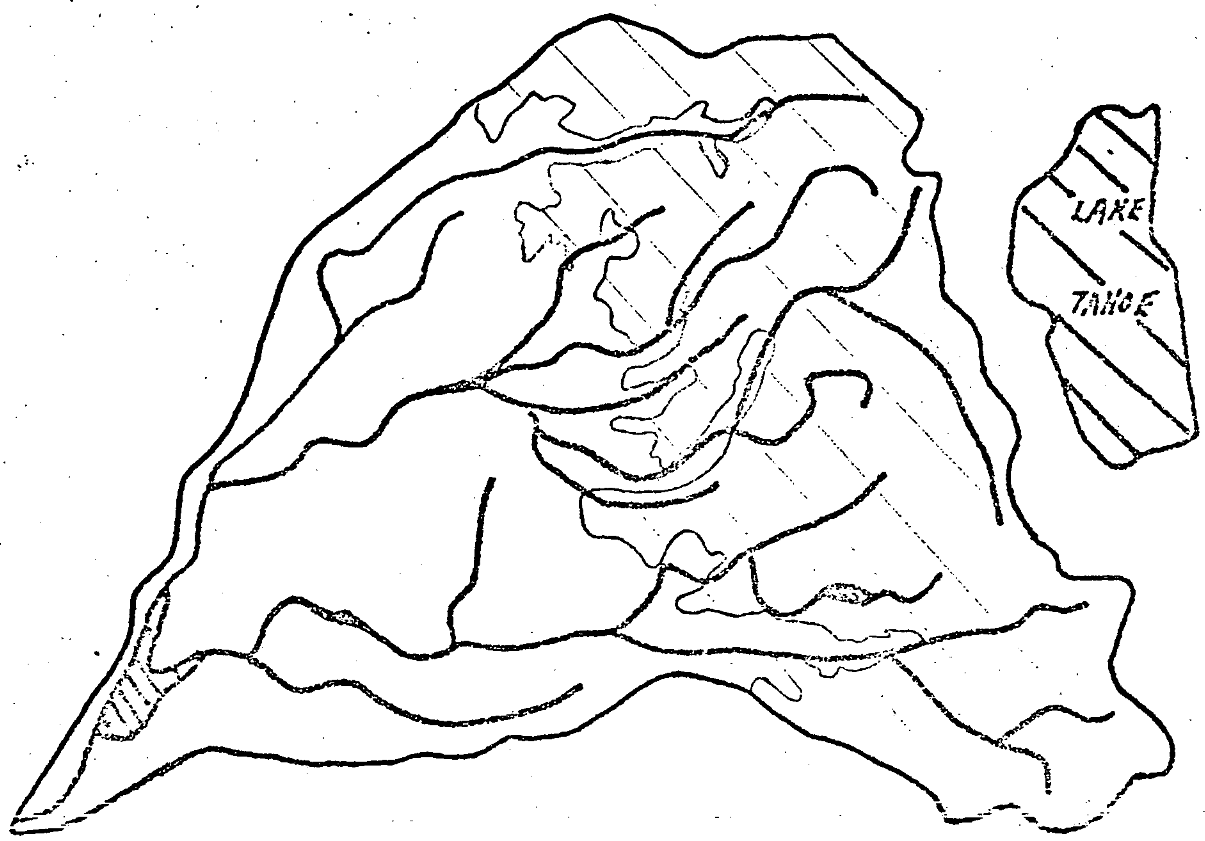
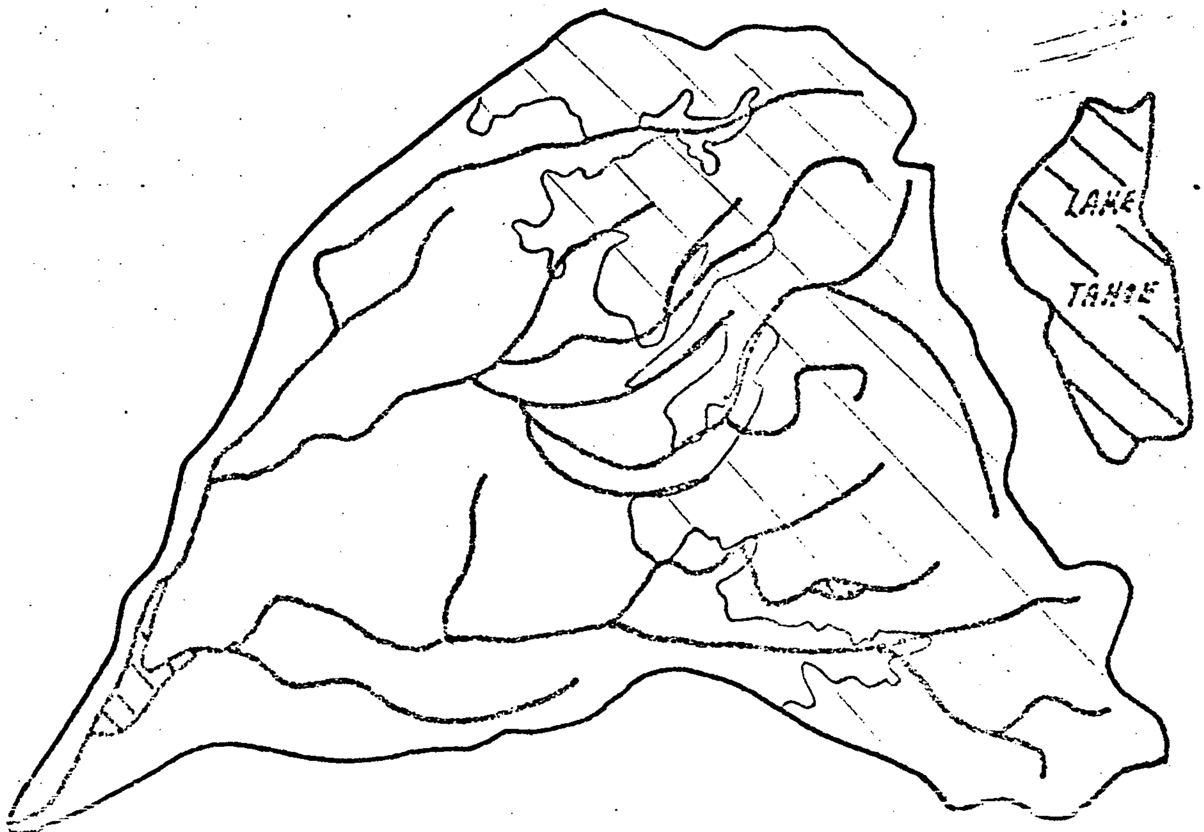


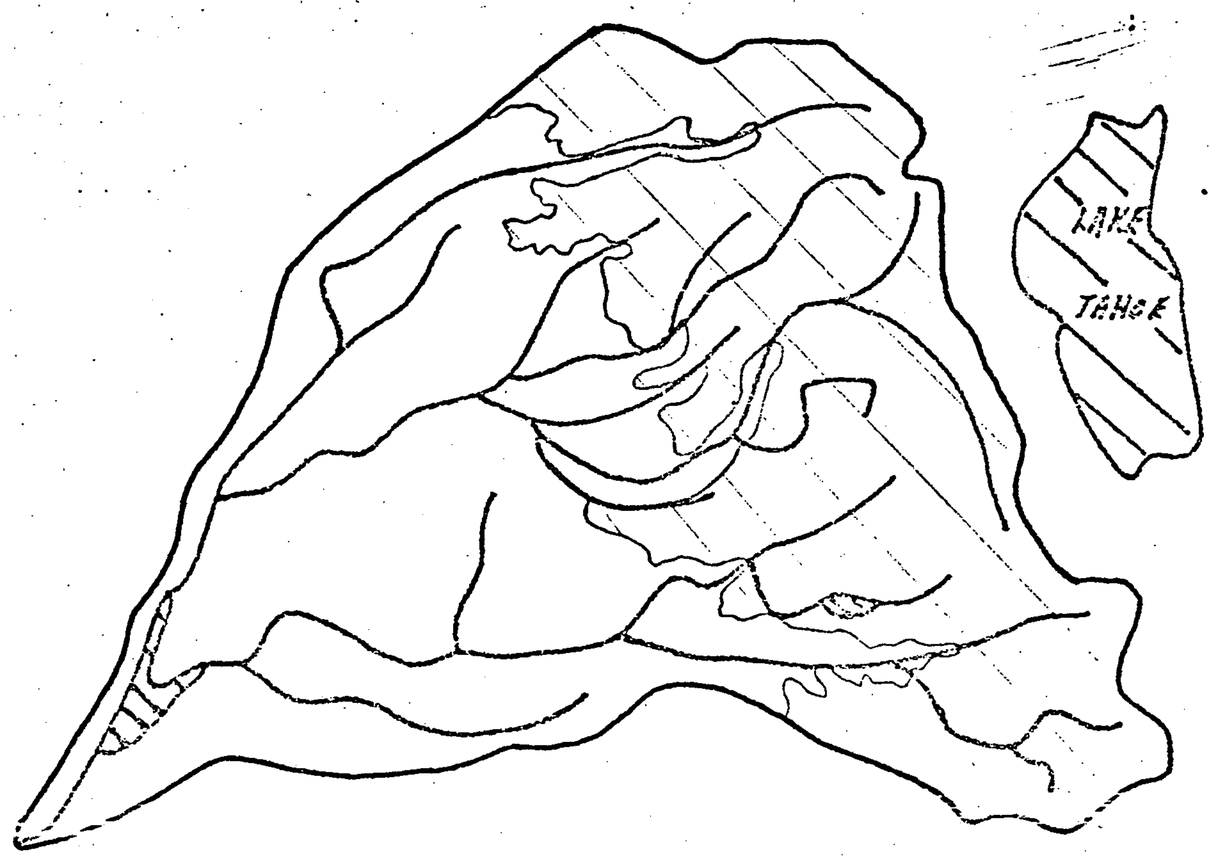
Figure la.

American River Basin
16 March 1973
Interp by WM
From ERTS Orbit 3291
1236-18122 MSS 4
Percent snow cover 46%



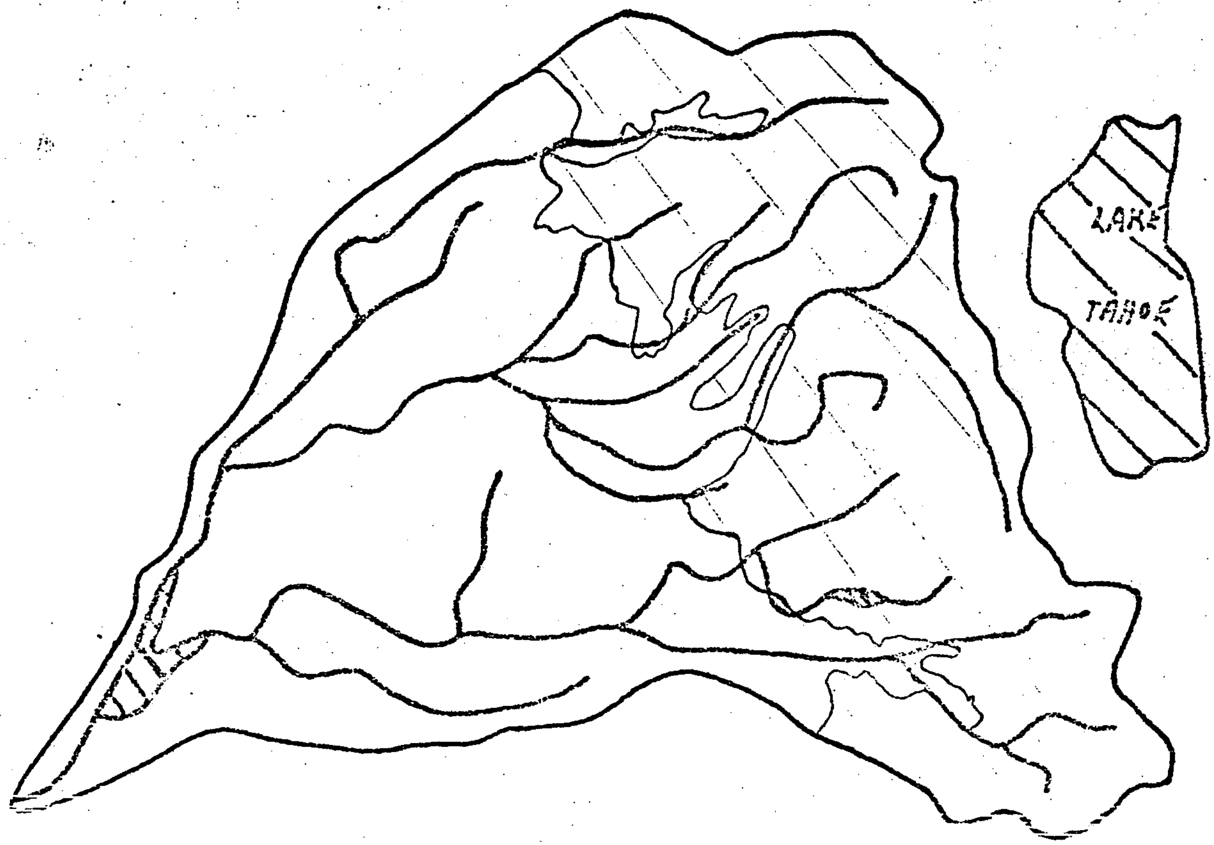
American River Basin
16 March 1973
Interp. by MM
From ERTS Orbit 3291
1236-18122 MSS 5
Percent snow cover 44%

Figure Ib.



American River Basin
16 March 1973
Interp. by MM
From ERTS Orbit 3291
1236-18122 MSS 6
Percent snow cover 45%

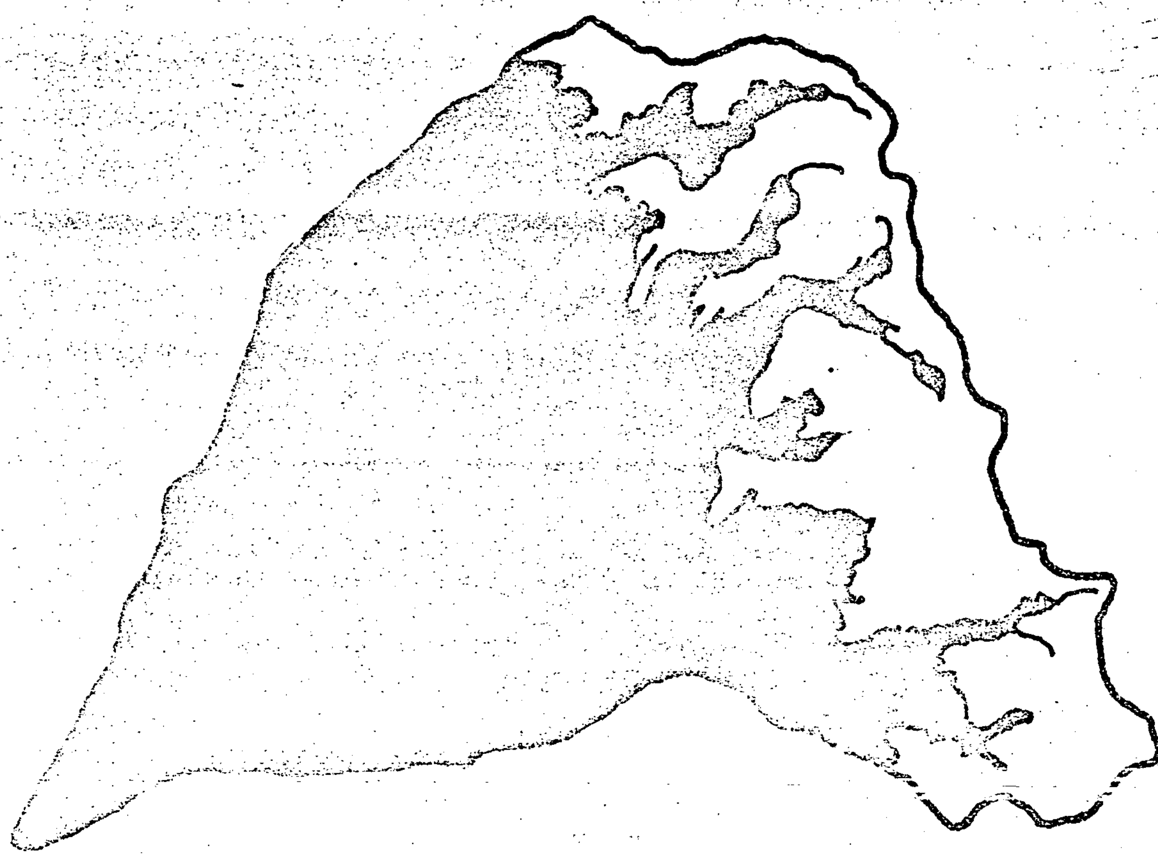
Figure 1c.



American River Basin
16 March 1973
Interp. by MM
From ERTS Orbit 3291
1236-18122 MSS 7
Percent snow cover 40%

Figure Id.

Figure 2. Example of snow mapping in the American River Basin (drainage area 2100 sq. mi.) based on ERTS-1 orbit 3542. The hatch portion of the figure represents the snow-covered area of the basin, amount to 50 percent, 3 April 1973



American River Basin
09 May 1973
Interp. by DGF
From ERTS-1 Orbit # 4044
1290-18121 MSS 4
Percent snow cover 26%

Figure 3.

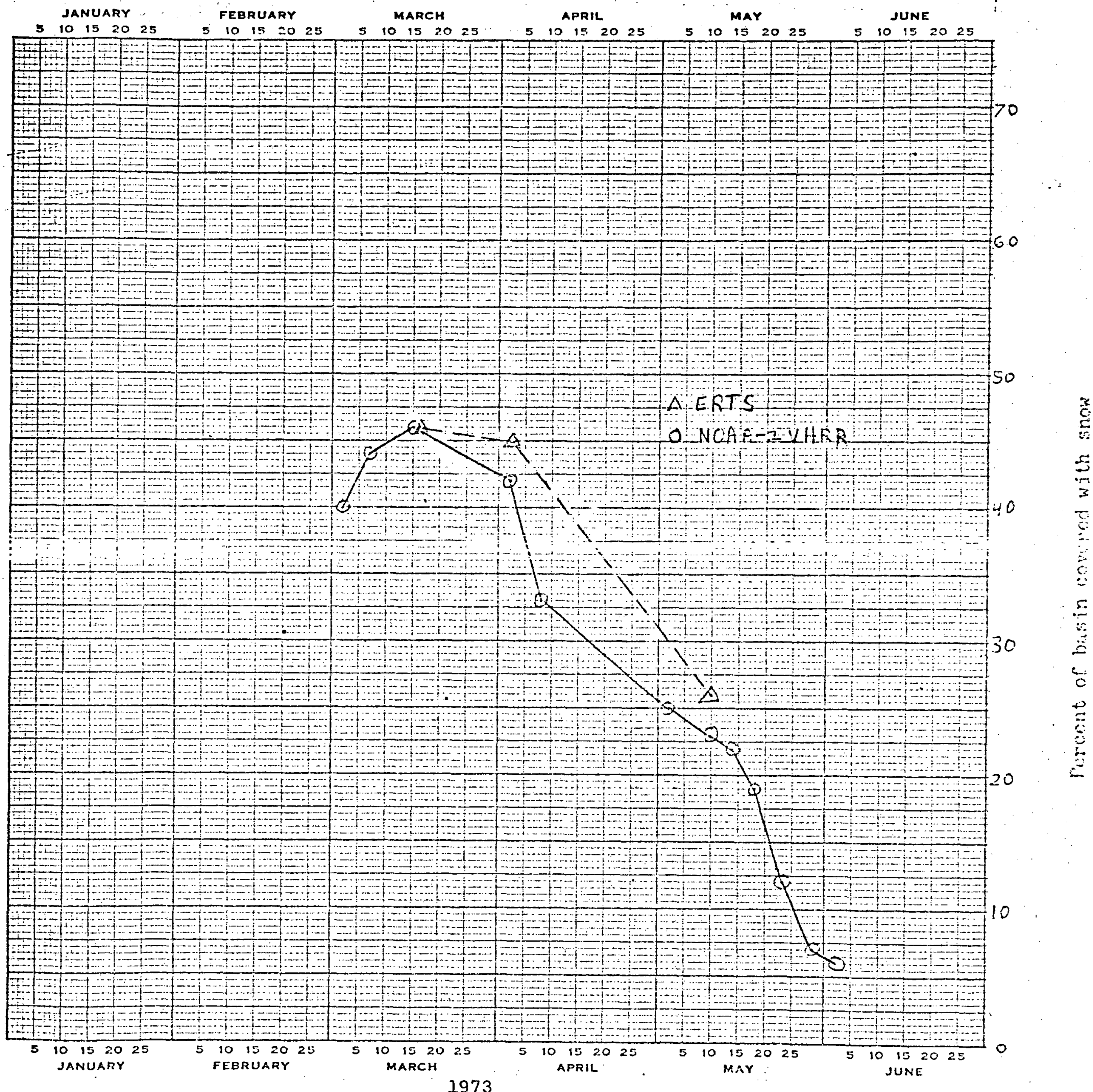


Figure 4. Comparison of snow cover mapping of the American River basin, California, by NOAA-2 and ERTS-1 satellites.

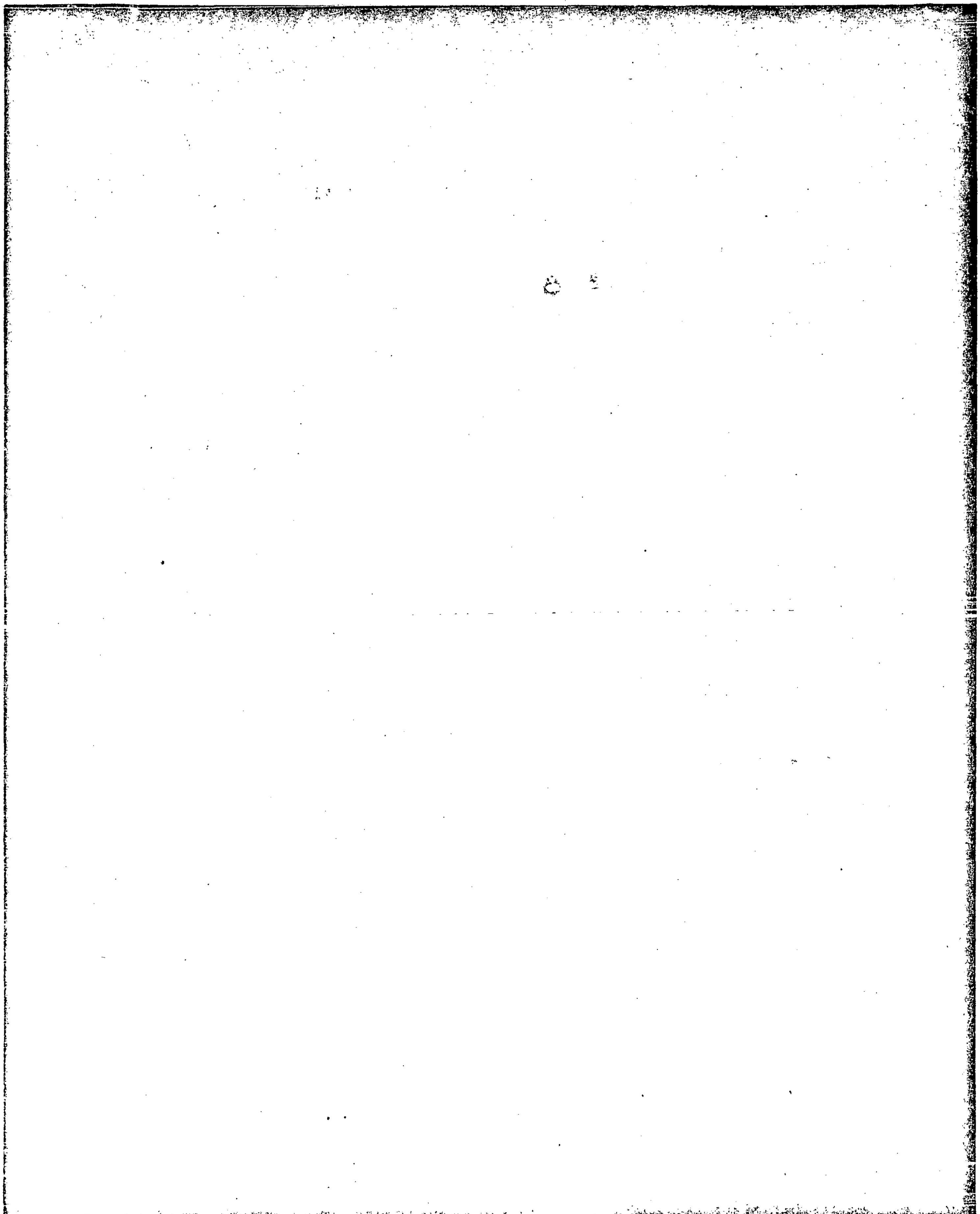


Figure 5

NOAA VHRR R/O 1802 3-9-73 IR #8

Figure 6. ERTS-1, band 7 (left)
band 4 (right), image
ID 1228-15422.